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16. Abstract

Research was carried out into two-phase titanium alloys. VT22 and VT14 alloys were investigated. It was found in VT14 that many defects occur in crystal structure when the alloy is heated. Defects disappear when the alloy is heated further to an almost annealed state. The VT22 alloy becomes brittle during aging when quenched from 1000°. Optimum thermally strengthening treatment is quenching from the $\alpha + \beta$-state, not higher than 700°, and subsequent aging.

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STRUCTURAL TRANSFORMATIONS IN TWO-PHASE TITANIUM ALLOYS[1]

E. V. Polyak and A. Yu. Sokolova

The kinetics of decomposition of the metastable martensitic /66*
α'-phase and β-phase in two-phase titanium alloys was studied with an electron microscope. The results obtained determined a link between the structural transformations and the mechanical properties of the alloys. The structure of the α'-phase and the kinetics of its decomposition were investigated in a VT14 alloy after quenching in water from the β-state at 1000° and subsequent aging in temperature intervals of 550-750°.

It is known that in two-phase alloys of this type, where the concentration of β-stabilizers is much less than the critical, martensitic transformation occurs when quenching in water from the β-state. A metastable α'-phase forms, which has a hexagonal, densely packed lattice, the parameters of which are close to those of a low-temperature α-modification of titanium. The structure of the alloy in this state is characterized by the rapid increase of β-grains and the formation of a well-outlined relief within the grains, which, when examined through an optical microscope look like fine, long needles, oriented in each fragment of the grain, typical of the martensitic phase. In some investigations into the structure of titanium alloys using an electron microscope, it was seen that the martensitic phase has a laminar formation with a very complex and fine structure [1, 2, 3]. Fig. 1 shows the most typical structures of the martensitic α'-phase in a VT14 alloy after quenching in water from 1000°. Martensitic plates are often found, containing a great number of fine twins of the {1011} system (Fig. 1, a). An outstanding feature is the intersection

[1] V. N. Moiseyev and Ye. V. Znamenskaya took part in the work.

* Numbers in the margin indicate pagination in the foreign text.

Fig. 1. The structure of alloy VT14 after quenching in water from 1000° (a-c) and the structure of a VT14 alloy after quenching in water from 1000° and aging at 550-750° (d-h), x 35,000.
a. Twins in α'-martensitic plates; b. dislocations in α'-martensitic plates; c. subgrains in α'-martensitic plate; d, e. aging at 550°, for 4 hours; f. aging at 600°, for 4 hours; g, h. aging at 750°, for 2 hours, x 10,000.

of twins on the boundary between the two plates, which are in twin orientation to each other. This boundary formation can be one of the reasons for the brittle failure of a VT14 alloy on the boundaries of the martensitic plate during expansion. The high density of dislocations (Fig. 1, b) is also characteristic of a structure with several α'-phase plates. Often, coarse plates of the α'-phase consist of elongated subgrains, almost parallel to the plate itself (Fig. 1, c). There is also a high density of dislocations in subgrains. The great density of the defects and the complex fine formation of the α'-phase determine the high strength of the alloy in a quenched state and the low plastic properties.

The mechanical properties of alloys with a martensitic structure change little during subsequent heating to 550-600°, whereas alloys with a metastable β-phase (VT14 after quenching from 800-850°, VT15 and others) are considerably weakened in this temperature interval. Radiographic investigation has shown that during the heating process at 550-600°, there is a decomposition of the metastable α'-phase, which has the following characteristic features. /68

1. Decomposition occurs in the limits of the initial plates of the α'-phase, and the stability of the boundaries of these plates is maintained up to 750-800° (Fig. 1, d-h).

2. The beginning of a new phase occurs in defects of the lattice inside the martensitic plates -- on twins, dislocations, boundaries of subgrains and plates (see Fig. 1, d-e).

3. As the aging temperature is increased to 600°, boundaries of subgrains, and also martensitic plates, become wider, the outlines of the prominent phase become more clear, and the density of dislocations is decreased (see Fig. 1, f).

4. A further increase in the heating temperature of a quenched alloy to 750° causes a considerable annihilation of defects: twins and subgrains disappear, and the density of dislocations is considerably reduced. However, the boundaries of primary α'-plates are retained. A characteristic feature of this stage of aging is the formation of relatively coarse needles of the new phase in the center of the plate and zones, free of segregations and probably enriched by β-stabilizers [4]. The decomposition process is completed with the formation of equilibrium of the structure, consisting of a mixture of laminar deposits of the α- and β-phases (see Fig. 1, g-h).

In this way, martensitic transformation in two-phase titanium alloys is accompanied by the formation of many defects of crystal formation (subgrains, twins, dislocations), which greatly affect the kinetics of decomposition of the martensitic α'-phase. These defects, especially on the boundaries of plates, are stabilized by the β-phase and are preserved to high aging temperatures ($\sim$ 600°). In this respect, the strength is maintained, and there is no significant increase in the plastic properties. Defects occur only at a temperature, corresponding practically to an annealed state, and there is a shift to an equilibrium structure, consisting of laminar deposits of the α- and β-phases. Decomposition occurs by the local redistribution of the alloying elements in the limits of the matrix plates of the α'-phase.

The decomposition of the metastable β-phase was examined in a deformed VT22 alloy, containing a critical concentration of β-stabilizers. It is known that in this alloy, after quenching from the β-state, the β-phase is fixed. Subsequent aging causes an almost complete loss of plasticity. Comparison with the structure of alloy VT22 (Fig. 2, a) after quenching in water from 1000° and aging at 550°, for 4 hours, shows that there is decomposition of the metastable β-phase, with the formation of a large number of highly dispersed needle-shaped segregations of the α-phase accurately oriented in two directions and evenly distributed in the die. The formation of this highly dispersed decomposition leads to a sharp increase in resistance to movement of dislocations and a reduction in the plastic properties during repeated expansion. After quenching in water from the α + β-state at 700°, the structure of the VT22 alloy consists of a mixture of fine polyhedral crystals of the α- and β-phases in a quantitative ratio of ∿ 1:1. This quenching temperature is insufficient for complete recrystallization of the deformed material -- there is a relaxation of stresses, which can be seen by the formation of polygonal walls (Fig. 2, b).

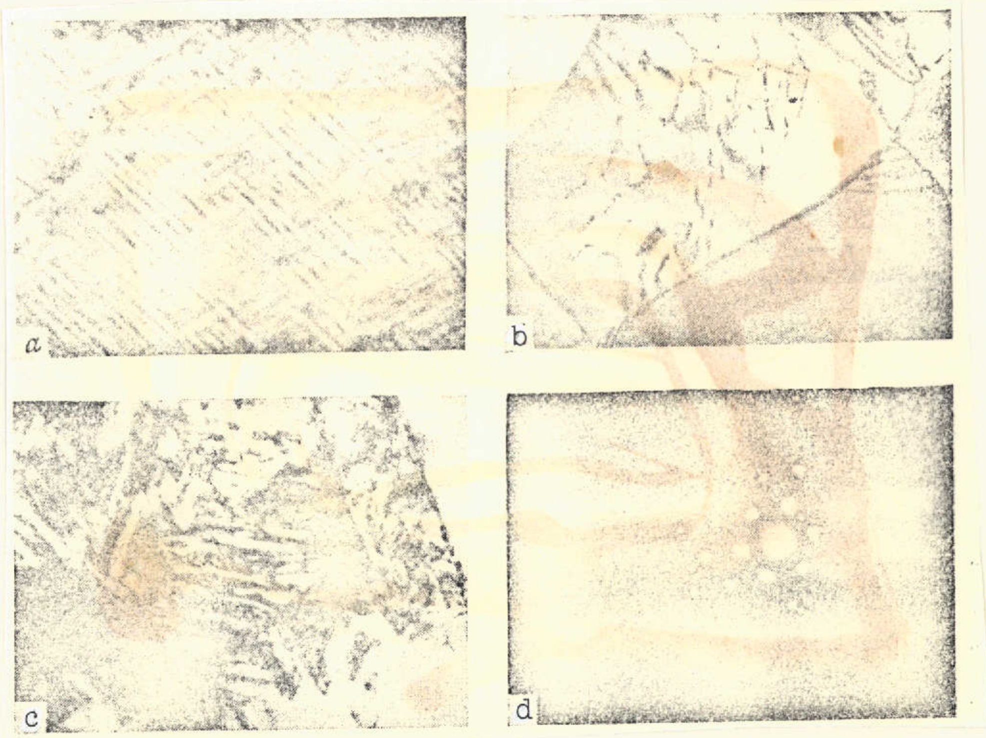

Fig. 2. The structure of the VT22 alloy, x 35,000. a. After quenching in water from 1000° and aging at 550°, for 4 hours; b. quenching in water from 700°; c. Quenching in water from 700° + aging 450°, for 8 hours; d. microdiffraction from the VT22 alloy after quenching from 800° and aging at 350°, for 9 hours.

The following features are characteristic of a decomposition in the aging process of a metastable β-phase in the VT22 alloy, quenched from the α + β-state.

1. The short heating of the alloy quenched from 700° for 9 hours at a temperature of 300° causes the further development of the polygonization process, which is seen by the increase in the number of subgrains, the boundaries of which consist of polygonal dislocation lattices.

2. The increase in the aging temperature to 450° causes significant structural changes. Dislocations disappear inside and on the boundaries of subgrains, and there is an intense decomposition process of the metastable β-phase, when a new phase develops in the form of needles along three directions $[110]_\beta$ (Fig. 2, c). Heating at a temperature of 550° causes considerable coagulation and some dissolution of particles of the α-phase. /69

3. At a higher quenching temperature from the α + β-state, 800°, there is a relaxation of stresses from the previous deformation of material, and there is no polygonal substructure formation. A metastable β-phase forms, characteristic of this condition, which decomposes during subsequent heating in temperature intervals of 300-350°, which was established by X-ray diffraction analysis, and also by radiographic electron microscope and microdiffraction methods (Fig. 2, d).

In this way, the decomposition of the metastable β-phase during aging of the VT22 alloy, quenched from 1000°, with the formation of a mixture of dispersed segregations of α- and β-phases, causes the material to become very brittle. The best thermal strengthening treatment is quenching from the α + β-state (not higher than 700°) and subsequent aging, since a multiphase structure is formed, consisting of disperse segregations of the primary α-phase and highly dispersed decomposition products of the metastable β-phase. Research showed that decomposition products of this phase coagulate and dissolve at a much lower temperature than those of a new phase, formed as the result of the decomposition of α'-martensite.

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